Comparison of Direct and Indirect Implant Accuracy Assessment Methods Using CodiagnostiX Software for Single Implant Placement an In Vitro Study

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Abstract

Static computer-aided implant surgery (s-CAIS) has been introduced to implant dentistry for ages. According to previous studies, they were recognised by inaccuracies of actual implant position placed via using a static computer-aided implant system. These inaccuracies result from an accumulation of every step in the workflow from planning to accuracy assessment. Recently, there are two methods, direct and indirect, to assess deviation between planned and placed position. The accuracy assessment method had been reported to be one of the influencing factors leading to deviation in implant position. Up until these days, there is no study compared between direct (pre and post CBCT superimposition) and indirect (using impression or intraoral scanning) methods of implant position measurement in one study. Thus the accuracy between these two methods of accuracy implant position analysis should be evaluated. *Objective:* The purpose of this study is to compare between the direct and indirect accuracy assessment method of 3-dimensional computer-guided implant placements using the coDiagnostiX software. *Methodology:* 10 bone level tapered implants (Straumann) were placed on the single edentulous space maxilla model which has been planned with coDiagnostic software. The samples were divided into two groups. Group one, 10 placed implants were superimposed to the planned by using pre operative CBCT and post operative CBCT. Group two, the identical 10 placed implants of sample in group one were scanned by using a scanned body to generate the placed implant positions. Then the planned and placed implant positions were superimposed. The deviation among the two groups were measured and compared. *Result and Discussion:* Regarding the direct method, this study found the mean of the horizontal coronal deviations 0.58 mm, the horizontal apical deviations 0.73 mm, the mean vertical deviation 0.48 mm, and the mean angular deviations 1.01 degrees. For the indirect method, the mean horizontal coronal deviations was 0.65 mm, the horizontal apical deviations was 0.80 mm, the mean vertical deviation was 1.51 mm, and the mean angular deviations was 1.72 degrees. No significant differences were found in all parameters, angular deviation, linear coronal deviation, linear apical deviation, and vertical deviation ($P > 0.05$). *Conclusions:* In conclusion, there is no statistically significant difference between direct and indirect method to measure implant deviation between planned and placed implant position via using coDiagnostiX software.

Keywords**:** *Accuracy assessment, CAD/CAM surgical template, computer-aided surgery, dental implants, guided implant surgery, surgical guide template*

1. Introduction

Implant dentistry has been introduced into the field of dentistry to be one of the treatment options for replacing missing dentition for decades. Implant placement in the anterior maxillary region was extremely critical and challenging for the clinician due to esthetic demand and limited bone architecture. The deviation in linear and angulation of implants can lead to loss of buccal bone which is one of the factors that contribute to the aesthetic sustainability of implants (Buser, Martin, & Belser, 2004; Block, 2015). According to the prosthetic-driven implant placement concept, the conventional implant placement technique can be done by using radiographic templates which is obtained from diagnostic wax up model in order to provide the relationship between the expected final restoration and crestal bone. However, one of the major disadvantages of the conventional method is that the systems do not present complete 3-dimensional (3D) implant positioning during the surgical procedure. With this technique, the clinician place implants freehandedly when performing surgical procedures, hence the precise angulation and depth of the implant can be achieved from the surgeon's skill. The depth of the implant in anterior region is a significant factor for creating emergence profiles for final restoration. Angulation of the implants in anterior teeth is an important factor to determine angulation of the abutment, especially in multiple restoration implant supported cases. Computer-aided design and computer-aided manufacturing (CAD/CAM) technologies become helpful tools to overcome these limitations of conventional implant placement techniques (Tahmaseb, Wismeijer, Coucke, & Derksen, 2014). Computer assisted implantation systems have been purposed in order to achieve accurate 3-dimension preoperative analysis of anatomical structure along with virtual planning related to the prosthetic perspective, and subsequently transfer the planned implant position to the surgical phase (Behneke, Burwinkel, & Behneke, 2011).

At present, there are 2 categories, static and dynamic, of computer assisted implantation systems (CAIS) available. Both methods will be advantageous compared with the conventional method (Kramer, Baethge, Swennen, & Rosahl, 2004; Farley, Kennedy, McGlumphy, & Clelland, 2013; Tahmaseb, Wu, Wismeijer, Coucke, & Evans, 2018). A static system uses CBCT image combines with CAD/CAM technology to generate a surgical guided template with sleeves (metal cylinders) and a surgical system that uses coordinated instrumentation to place implants. While a dynamic navigation systems use optical technologies to track the patient and the hand piece and to display images onto a monitor, in order to place the implant into the planned position. According to the previous studies, Ruppin et al. (2008) compared accuracy of implant placement using two dynamic systems and one static system. No statistical significant differences were found between these three systems. However, dynamic navigation requires multiple registration sequences that contain many potential sources of error. Thus this navigation system requires a learning curve of clinicians to achieve proficiency. All these reasons caused static navigation system more favourable among clinicians.

Implant placement via guided static CAIS has many advantages including precision, and low investment cost (Gulati, Anand, Salaria, Jain, & Gupta, 2015; Sicilia & Botticelli, 2012). However, deviation between the planned and placed implant position still is the most significant problem of computer assisted implantation systems. The inaccuracy can be caused by accumulation of compounded error from the planning phase, surgical guide fabrication phase, surgical phase, and the accuracy analysis phase.

The accuracy analysis method can be categorised into two main methods as direct and indirect method. The direct method can be performed by superimposition of pre-operative CBCT images with a planned implant and post-operative CBCT images with an actual placed implant. On the other hand, the indirect method determines deviation by using pre-operative CBCT images to superimpose onto the implant position which is generated from impressions or intraoral scanning through the impression coping or scanned body. The advantage of this method over the direct method is the patients do not have to expose the CBCT after implant surgery. However, this method could create errors from the inaccuracy of intraoral scanner or from not correctly connecting between the impression coping or scan body to the implant. According to Pyo, Lim, Koo, & Lee (2019) accuracy analysis method claimed to be one of the influencing factors leading to deviation in implant positions. Thus the accuracy between these two methods of accuracy implant position analysis should be evaluated.

Recently, there are numerous commercially available implant planning software. Some software programmes provide a tool to evaluate accuracy between planned and placed implant position, while some software programmes have no method to do so. Currently, there is no other software except coDiagnostiX (Dental Wings Inc, Montreal, CA) that provides 2 approaches, direct and indirect method, to assess accuracy between virtual planned and actual placed implant position. CoDiagnostiX (Dental Wings Inc, Montreal, CA) is one of the worldwide used software which allows clinicians to compare between virtual planned and actual placed implant position via the treatment evaluation tool.

2. Objectives

The purpose of this study is to compare between direct and indirect accuracy assessment methods of 3-dimentional computer-guided implant placement using the coDiagnostiX software.

3. Materials and Methods

This study was performed at the Department of Esthetic Restorative and Implant Dentistry Chulalongkorn University.

3.1 Planning Procedure and Surgical Template Fabrication

A total of ten drillable polyurethane maxillary models (Figure 1) from left to right second molar with edentulous space on right central incisor were fabricated. All 10 models were fabricated separately with the same protocol. Diagnostic wax was made at the edentulous space of each model. Digital imaging and Communication in Medicine (DICOM) files of the CBCT images (iCAT^{TM} , Imaging Science International, Hatfield, PA, USA) and Stereolithography (STL) file derived from the model scan (inEos X, Dentsply Sirona, York, Pennsylvania, United States) of each model and was transferred to the coDiagnostiX software (version 9.10, Dental Wings Inc, Montreal, CA) by the superimposition procedure. The superimpositions were performed with a minimum 3-point registration procedure and the correspondence between the CBCT image and model scan were evaluated in the verification step. In each implant position planning, a 3-dimensional of Straumann 3.3*10 mm BLT implants (Straumann, institute Straumann AG, Basel, Switzerland) was utilized at the edentulous space. In order to control the height of the sleeve and the length of the guided instruments used in all models, the position of the implant shoulder were planned at the crest of model cast consistently. After that, the surgical stents were designed to incorporate full maxillary arch with H4 protocol and 4 inspecting windows.

Then the surgical guided templates were fabricated by 3D printing (Dental Prime, Stratasys, Rehovot, Israel) (Figure 2).

Figure 1 Ten drillable polyurethane maxillary models

Figure 2 Surgical guided template

3.2 Implant Placement

At the time of implant placement, each surgical guided template was fitted onto its respective model. The adaptability of surgical guided template was examined via inspecting windows, and the tip of explorer was not allowed to penetrate through any inspecting window. Before the implant was placed, the maxillary model was mounted on a Nishim head to simulate an intraoral situation. 1 operator placed Straumann 3.3*10 mm BLT implant into each model according to a manufacture guided surgery protocol using the Straumann BLT guided surgery kit.

3.3 Implant Position Accuracy Analysis

After the implant was place, each model was performed with two assessment methods of accuracy analysis of implant position. The first and second methods were categorised in group 1 and group 2 respectively. For group 1, the model was rescanned using CBCT. Then the DICOM file of CBCT image was superimposed onto the original startup treatment plan in coDiagnostiX software using CBCT mode of Treatment Evaluation tool. For group 2, the model was scanned using a 3Shape intraoral scanner with scan body (CARES® NC Mono Scan body, Straumann, Basel, Switzerland) attached to the implant. The adaptability of implant platform and scan body was examined. Then STL file of 3D cast was superimposed onto the original startup treatment plan in the software using the scan body mode of Treatment Evaluation tool.

In each assessment method, four measuring points were used to compare the deviation between virtual planned and actual placed implant positions. :

- Linear deviation at the entry point of the implant (mm), measured at the center of the implant
- Linear deviation at the apex of the implant (mm), measured at the center of the implant
- Linear deviation in height/depth of the implant (mm)
- Angulation deviation of the axis of the implant (degree)

3.4 Statistic Analysis

All measurement data was gathered and entered in IBM SPSS Statistics software (version22 software SPSS Inc., Chicago, IL). Mean difference between planned and actual implant position of two groups were compared using Wilcoxon Signed Rank Test. P-value less than 0.05 ($P < 0.05$) will be considered as significantly different between two groups.

4. Results and Discussion

4.1 Results

In each assessment method, four following measuring points were collected for comparison the deviation between virtual planned and actual placed implant positions. :

- Angulation deviation of the axis of the implant (degree)
- Linear deviation at the entry point of the implant (mm), measured at the center of the implant
- Linear deviation at the apex of the implant (mm), measured at the center of the implant
- Linear deviation in height/depth of the implant (mm)

The mean and standard deviation of linear and angular deviation obtained from two assessment methods, direct and indirect, are demonstrated and compared in Table 1. Due to the small sample size, the Wilcoxon Signed Rank Test was used in all outcomes. The null hypothesis was set as there is no difference between the scan body group and CBCT group. The null hypothesis were accepted. No significant differences were found in all measuring points, angular deviation, linear coronal deviation, linear apical deviation, and vertical deviation ($P > 0.05$) (Table 2).

Table 1 Mean, maximum, minimum, standard deviation of different parameters evaluated for direct and indirect groups

Parameter	**Direct**			**Indirect**		
	Maximum	**Minimum**	**Mean ± SD**	**Maximum**	**Minimum**	**Mean ± SD**
Angulation (degree)	3.90	0.60	1.01 ±1.18	3.60	0.60	1.72 ± 1.19
Horizontal coronal (mm.)	0.99	0.36	0.58 ± 0.18	0.95	0.37	0.65 ± 0.15
Horizontal apical (mm.)	1.03	0.37	0.73 ± 0.23	1.45	0.45	0.80 ± 0.27
Vertical (mm.)	0.92	0.06	0.48 ± 0.22	0.64	0.18	0.51 ± 0.16

Table 2 P-value of the comparison of the accuracy in different analyzed parameters of the implants position measured from direct and indirect method

Parameter	**P-value**
Angulation (degree)	0.55
Horizontal coronal (mm.)	0.14
Horizontal apical (mm.)	0.48
Vertical (mm.)	0.26

4.2 Discussion

Recently, there are several methods to assess the accuracy of dental implant positions in computer assisted implant placements. They can be divided into two main categories. The first method can be done directly by superimposition between pre-operative CBCT images and postoperative CBCT images with a planned and placed implant in position respectively (Pyo et al., 2019). While the second technique is using the impression method, which could be achieved via impression coping or scanned body in order to acquire implant positions indirectly. Clinically, the advantage of the direct method over the indirect method is it could be perform at any time, while the indirect method could be conducted on the same day of surgery or after the healing period. Because the impression coping or scanned body has to connect with the fixture, the osseointegration should be completed prior to the connection to prevent the loss of osseointegration while connecting to the scanned body to the fixture. However, this article was performed in vitro, as the time of data collection was not the concerned factor. Apart from the time of data collection, in clinical situations which implant had been placed deeper than in this experiment, it is improbable to examine the adaptability between the scanned body and the implant platform.

By using the treatment evaluation tool of coDiagnostix software, the result showed no statistically significant difference between the direct and in direct method (Table 2). However when superimposed the result from the direct (Figure 3) to the indirect (Figure 4), there is deviation between these two placed implant positions (Figure 5 b,c). This deviation can be caused by using intraoral scans and superimposition of STL files to CBCT images of the indirect method. Up to date, there is no study compared between the direct (pre and post CBCT superimposition) and indirect (using impression or intraoral scanning) methods of implant position measurement in one study. Each previous study demonstrated either the direct or indirect method to compare between planned and placed implant positions. Deeb et al. (2017) who performed the indirect method, reported mean faciolingual angular deviation of 3.37 degrees, mean faciolingual direction of 0.49 mm. The results of this study (mean linear deviations of 0.65 at the platform and 0.8 mm at the apex, mean angular deviations of 1.72 degrees; Table 1), are within the range of the reported data. Regarding using the direct method, Rungcharassaeng, Caruso, Kan, Schutyser, & Boumans (2015) reported the overall deviation at platform of 0.64 mm., at apical of 1.22 mm. and angular deviation of 1.22 degree. The results of this study are within the range of the reported data. The important key to choose between direct and indirect method is the software used. Typically, the direct method could be done by using the providing option in planning software. Like NobelClinician and coDiagnostiX, these two software programs allowed clinicians to superimpose planned and placed implant position directly within the software. The indirect method could be performed using the same software as planning software or using other software to do so. If the software allows a clinician to superimpose in the planning software, such as Implant Studio (3 Shape, Copenhagen, Denmark), codiagnostiX, these procedures could be performed with in the software. Other reasons to select the indirect method is that using the software did not provide any tools to evaluate the placed implant positions.

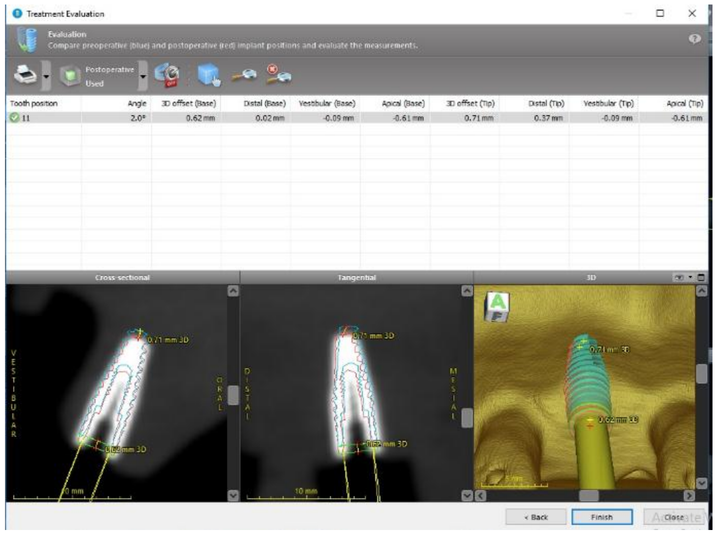

Figure 3 Treatment evaluation of direct method. Blue line represented planned implant position, Red line represented placed implant position from CBCT image

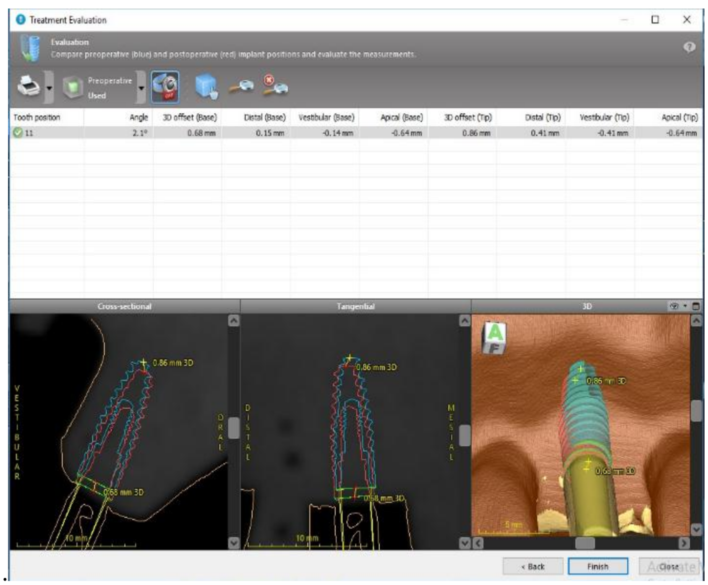

Figure 4 Treatment evaluation of indirect method. Blue line represented planned implant position, Red line represented placed implant position generated from scan body

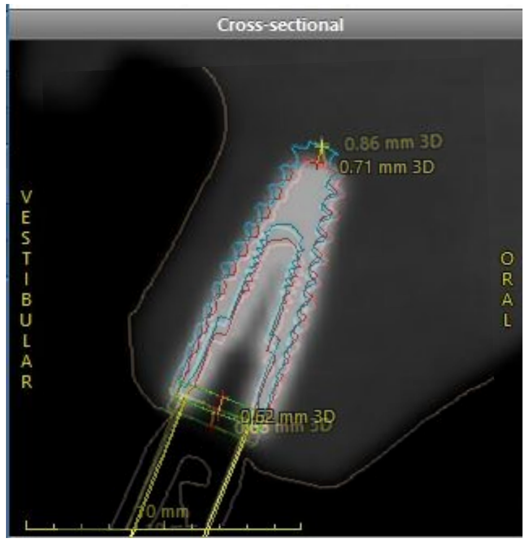

Figure 5 This figure represented the superimposition between direct and indirect method. (a) Blue line represented planned implant position. (b) Red line represented placed implant position from direct method. (c) Pink line represented placed implant position of indirect method,generated from scan body

This study was conducted in models, which claimed to achieve most precisely when compared to in vivo and cadaver studies (Bover-Ramos, Viña-Almunia, Cervera-Ballester, Peñarrocha-Diago, & García-Mira, 2018). The meta analysis that was done by Bover-Ramos et al. in 2018 found that the angular deviation was 2.39 ± 0.35 degrees. For the mean horizontal coronal, the deviation was 0.77 ± 0.15 mm. While the mean horizontal apical deviation was 0.17 ± 0.85 mm. And the vertical deviation was 0.61 ± 0.149 mm for in vitro studies. When the compared results were obtained from this experiment the results from Bover-Ramos et al. in 2018, the mean angular deviation, horizontal coronal deviation and horizontal apical deviation of this study are lower than that of Bover-Ramos et al., 2018. Meanwhile, the mean vertical deviation of this study is higher. Moreover, it is surprising that all of the placed implant positions achieved from this study were shallower than the planned. This is maybe due to the consistency of the model. The alveolar bone of the patient has 2 parts: cortex and medulla, which is softer than the cortex, while the models used in this study have only one consistency.

Currently, there are multiple available software programs in the field of computer-guided implantation systems (Mora, Chenin, & Arce, 2014). The first type is third-party implant planning software programs, such as Simplant (Materialise Dental Inc, Glen Burnie, MD, USA), Implant studio (3 Shape, Copenhagen, Denmark), Invivo5 (Anatomage, San Jose, CA, USA), NobelClinician (Nobel Biocare, Goteborg, Sweden), OnDemand3D (Cybermed Inc, Seoul, Korea), Virtual Implant Placement software (BioHorizons, Inc, Birmingham, AL, USA), coDiagnostiX (Dental Wings Inc, Montreal, CA, USA), and Blue Sky Plan (BlueSkyBio, LLC, Grayslake, IL, USA). Another type of planning software is provided by CBCT units such as Galileos system (Sirona Dental Systems, Inc, Charlotte, NC, USA), TxSTUDIO software (i-CAT!, Imaging Sciences International LLC, Hatfield, PA) and NewTom implant planning software (NewTom, Verona, Italy). One of the concerning factors when clinicians decided to use any software is the availability of each software in each specific region.

Several factors have been reported influencing the deviation of implant positions achieved from static computer assisted implantation systems. These include type of study, type of supporting template, and experience of the operator. Firstly, type of study (ie, cadaver, in vivo, or in vitro) had been reported to be one of the influencing factors for the implant accuracy. In vitro studies seem to have the most accuracy result from the better access. The second influencing factor is the type of template support which are tooth-supported, mucosa-supported, and bone-supported template. Behneke et al. (2011) reported that tooth supported templates have the lowest deviation. Lastly, operator experience can be one of the factors contributing to implant deviation (Rungcharassaeng et al., 2015). However, the difference between the two groups of this study was the measurement methods. Thus, it can be assumed that the results achieved from this study were influenced from the measurement methods.

The limitations of this investigation were that it was an in vitro study with a small sample size. Moreover, only coDiagnostiX software was used in this study. A further in vivo study with a larger sample size should be performed. And multiple software programs should be used to validate these findings.

5. Conclusion

Within limitations of this study, there is no statistically significant difference between direct and indirect methods to measure implant deviation between planned and placed implant positions via using coDiagnostiX software.

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